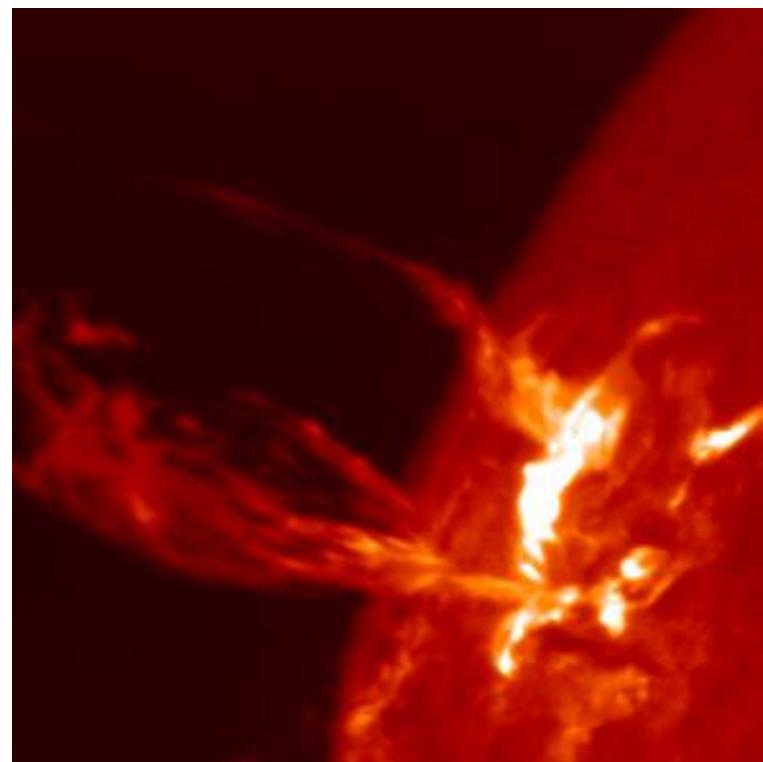


EURADOS Activities on Space Weather Effects: Comparison of Codes Assessing Radiation Exposure of Aircraft Crew during Solar Energetic Particle Events

EURADOS Working Group WG 11 / TG3
High Energy Radiation Fields / Solar Particle Events

Peter Beck on behalf of WG11 / TG3

Space Weather Week
13 – 17, April, 2015, Boulder, USA



Acknowledgements Contributors to TASK Group 3 (Status Feb. 2015)

Name	Institute	Country
Peter Beck	Seibersdorf Laboratories, SL	Austria
Pawel Bilski	Institute for Nuclear Physics, IFJ	Poland
Jean-Francois Bottolier-Depois	Institute for Radiological Protection and Nuclear Safety, IRSN	France
Rolf Bütkofer	University of Bern	Switzerland
Clive Dyer	Consultant, University SURREY	United Kingdom
Ernst Felsberger	IASON GmbH	Austria
Erwin Flückiger	University of Bern	Switzerland
Nicolas Fuller	Paris-Meudon Observatoire, LESIA	France
Karl-Ludwig Klein	Paris-Meudon Observatoire, LESIA	France
Alex Hands	University of SURREY	United Kingdom
Marcin Latocha	Seibersdorf Laboratories, SL	Austria
Vladimir Mares	Helmholz Zentrum München, HMGU	Germany
Daniel Matthiä	German Aerospace Center, DLR	Germany
Christian Pioch	Helmholz Zentrum München, HMGU	Germany
Günther Reitz	German Aerospace Center, DLR	Germany
Werner Rühm	Helmholz Zentrum München	Germany
Christian Steigies	University Kiel	Germany
Graeme Taylor	National Physical Laboratory, NPL	United Kingdom
Frank Wissmann	Physikalisch Technische Bundesanstalt, Braunschweig, PTB	Germany
Hiroshi Yasuda	National Institute of Radiological Sciences, NIRS	Japan

Co-Authors – EURADOS Report¹ Editorial Team (TG3)

Peter Beck	Seibersdorf Laboratories, SL	Austria
Jean-Francois Bottolier-Depois	Institute for Radiological Protection and Nuclear Safety, IRSN	France
Rolf Bütkofer	University of Bern	Switzerland
Erwin Flückiger	University of Bern	Switzerland
Nicolas Fuller ²	Observatoire de Paris, LESIA	France
Karl-Ludwig Klein ³	Observatoire de Paris, LESIA	France
Marcin Latocha	Seibersdorf Laboratories, SL	Austria
Vladimir Mares	Helmholz Zentrum München, HMGU	Germany
Daniel Matthiä	German Aerospace Center, DLR	Germany
Werner Rühm	Helmholz Zentrum München, HMGU	Germany

¹EURADOS Report: *Comparison of Codes Assessing Radiation Exposure of Aircraft Crew in Case of Solar Energetic Particle Events*

² until end of 2013

³ from 2014

Content

- Objectives WG11 / TG3
High Energy Radiation Fields / Solar Energetic Particles
- Discussion of two Ground Level Event investigations:
 - 1st Investigation: Definition in the style of GLE42 on 29 September 1989
 - 2nd Investigation: According literature data for GLE69 on 20 January 2005
- Preliminary Results
- Preliminary Conclusions and Future activities

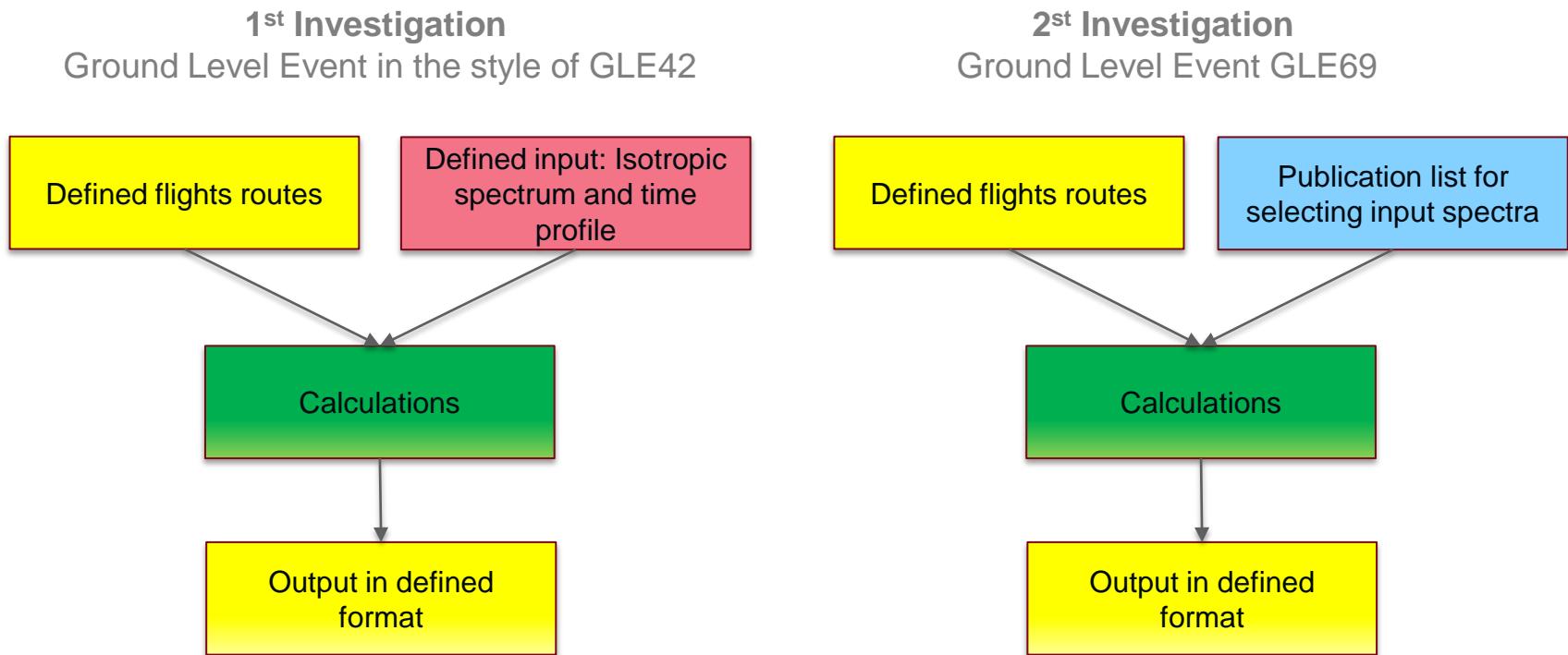
Objective EURADOS WG11/TG3

Improvement of the models for assessment of radiation dose during solar energetic particle (SEP) events and validation with experimental data

- SEP radiation dose code comparison for specific flight routes, based on flight routes used during WG11 / TG1¹
- Collection of information on action procedures in different EU countries.
- Harmonised action procedure in the case of a SEP event
- Report on results and discussion of investigations

¹J.F. Bottolier-Depois, P. Beck, M. Latocha, V. Mares, D. Matthiä, W. Rühm, F. Wissmann, *Comparison of Codes Assessing Radiation Exposure of Aircraft Crew due to Galactic Cosmic Radiation*, EURADOS Report, 2013-03, Braunschweig, May 2012.

Solar Energetic Particle (SEP) Code comparison for specific flight routes, based on flight routes used during WG11 / TG1¹

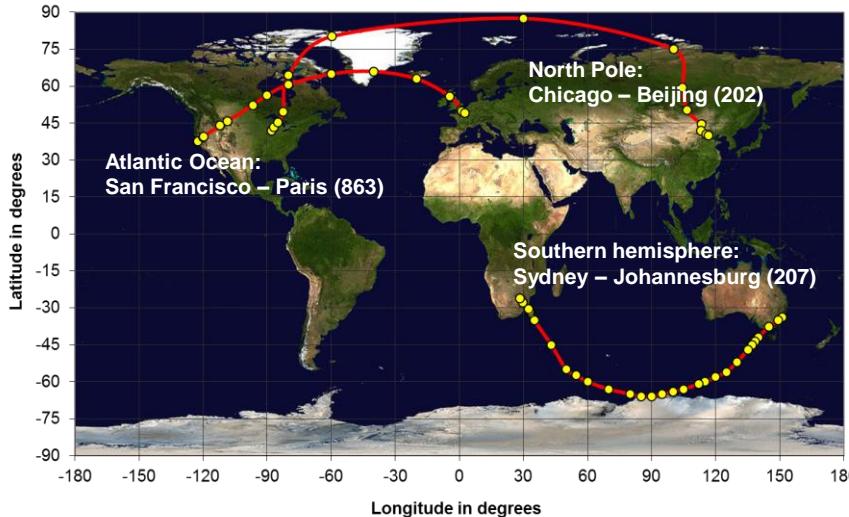


¹J.F. Bottolier-Depois, P. Beck, M. Latocha, V. Mares, D. Matthiä, W. Rühm, F. Wissmann, *Comparison of Codes Assessing Radiation Exposure of Aircraft Crew due to Galactic Cosmic Radiation*, EURADOS Report, 2013-03, Braunschweig, May 2012.

List of contributors and codes 1st and 2nd investigation

Institute / Organisation	Contacts	Code	Type of Code	contribute to Investigation
Royal Military College, RMC (Canada)	Hani Al Anid	PCAIRES	Non-Monte Carlo	1
University of Bern	Rolf Bütkofer, Erwin Flückiger	PLANTEOCOSMICS - Bern Model	Monte Carlo	1, 2
IASON GmbH	Ernst Felsberger	IASON-FREE	Non-Monte Carlo	1
University of SURREY	Alex Hands, Clive Dyer	QARM	Monte Carlo	1
German Aerospace Center, DLR	Daniel Matthiä	PANDOCA	Monte Carlo	1, 2
Helmholtz Zentrum München, HMGU	Vladimir Mares, Christian Pioch	GCR: EPCARD.NET SEP: GEANT4 Model	Monte Carlo	1
Physikalisch-Technische Bundesanstalt, Braunschweig, PTB	Frank Wissmann	FDOscalc	Non-Monte Carlo	1
National Institute of Radiological Sciences, NIRS (Japan)	Hiroshi Yasuda Sato	GCR: JISCARD-EX SEP: WASAVIES	Monte Carlo	1, 2
Seibersdorf Laboratories, SL	Marcin Latocha, Peter Beck	GCR: AVIDOS 1.5 SEP: SOLARDOS	Monte Carlo	1, 2
Observatoire de Paris, LESIA	Nicolas Fuller, Ludwig Klein	GCR: SIEVERT SEP: SiGLE	Non-Monte Carlo	2

Definition of flight routes, input / output data format



Input

Output

Input / Output Data:

- ASCII or Excel data sheet
- GCR, SCR, and GCR + SCR
- Dose, dose rate (μSv , $\mu\text{Sv}/\text{h}$)
- $H^*(10)$, E (ICRP-60, opt. ICRP-103)

Flight Num	Dep airport	Arr airport	Dep date	Dep UT	Arr date	Arr UT	Time from														GCR				SCR				GCR + SCR					
							FL		departure		lat		long		dH*(10)/dt				accumul	H*(10)	dE/dt	E	accumul	dH*(10)/dt	accumul	H*(10)	dE/dt	E	accumul					
															dH*(10)/dt	μSv/h	ICRP60	ICRP60	ICRP60	ICRP60	ICRP60	μSv/h	ICRP60	ICRP60	ICRP60	ICRP60	μSv/h	ICRP60	ICRP60	ICRP60	ICRP60	μSv/h	ICRP60	ICRP60
202	KORD	ZBAA	20.01.2005	05:30	20.01.2005	18:41	0	00:00	415800N	0875400W	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx
202	AER						290	00:18	431800N	0865100W	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	TOC						310	00:37	452400N	0845400W	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						330	01:11	494100N	0822400W	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						330	03:01	642400N	0800000W	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						350	05:04	801100N	0594800W	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						338	06:20	873100N	0300000E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						338	08:07	750100N	1001200E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						338	10:02	592600N	1043200E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						338	11:13	502000N	1062800E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						372	12:10	442700N	1131400E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	INT						363	12:30	415000N	1130900E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	TOD						363	12:49	402300N	1152900E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	
202	AER						0	13:11	400500N	1163500E	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx	xx.xx		

1st Investigation: Spectrum for different time windows of a Ground Level Event in the style of GLE42

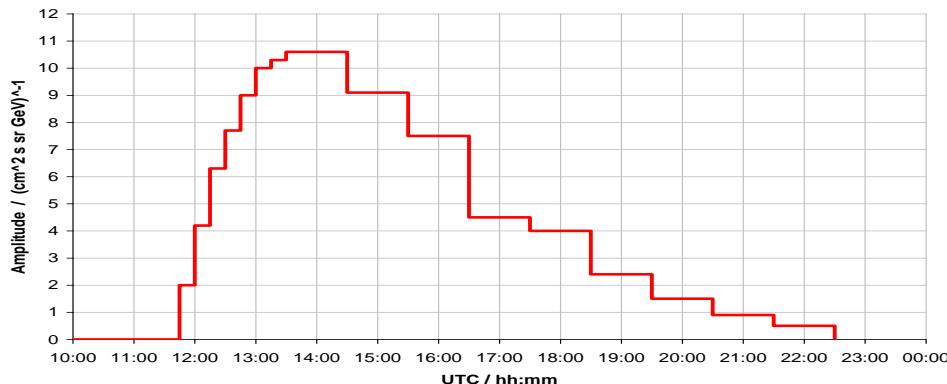
For rigidity, $P < 2$ GV: $J_{SCR}(P, t) = A(t) \cdot (P/GV)^{-\gamma}$

For rigidity, $P > 2$ GV: $J_{SCR}(P, t) = A(t) \cdot (P/GV)^{-(\gamma + \delta\gamma \cdot (P/GV - 2))}$

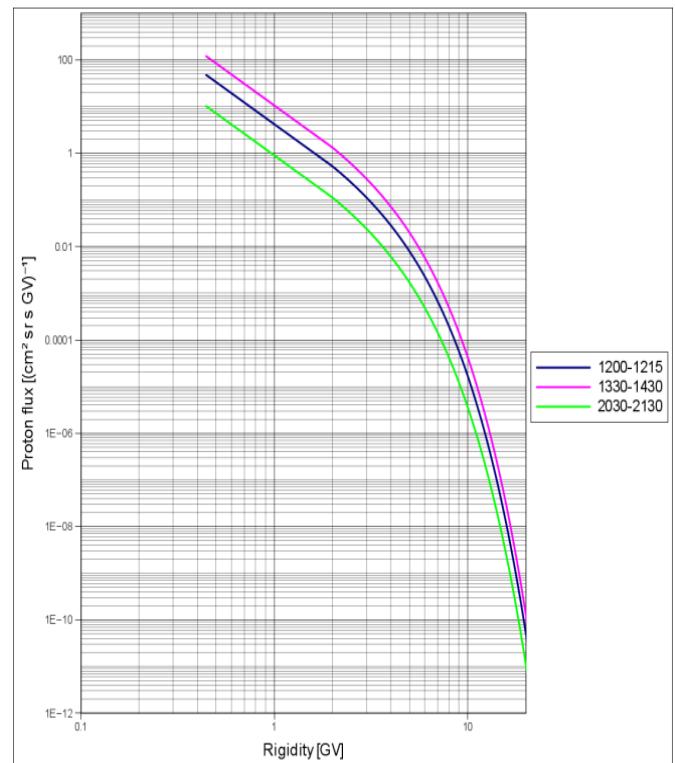
Assumptions:

- γ : 3.0, $\delta\gamma$: 0.3
- isotropy of solar particle flux in near-Earth space,
- constant spectral form,
- amplitude varying with time

$A(t)$ is given:



Proton input spectrum for time windows:
12:00 - 12:15, 13:30 - 14:30, 20:30 - 21:30



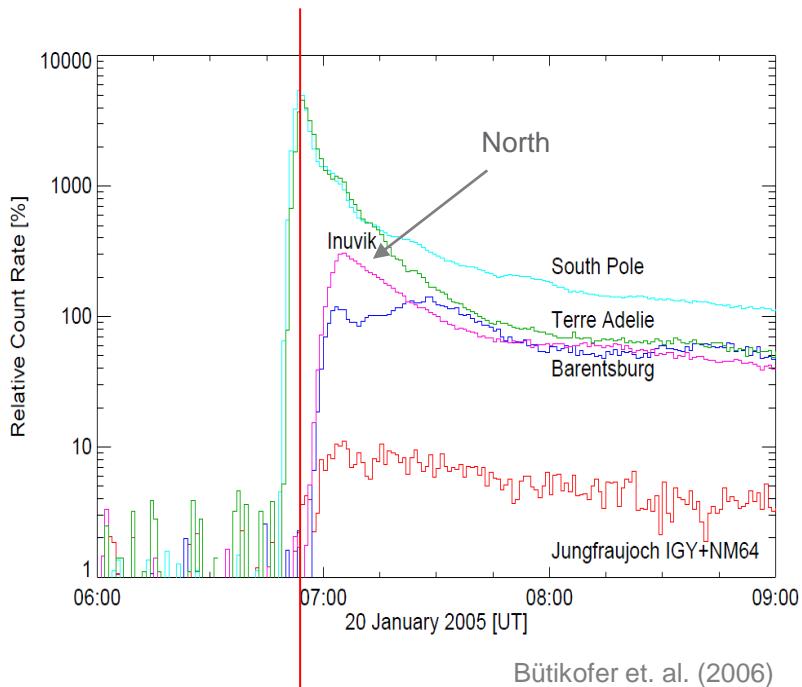
Ref: "Solar Cosmic Rays on 29 September 1989; An Analysis using the World-Wide Network of Cosmic Ray Stations" D.F. Smart et al., ICRC, Vol. 3, pp. 97-100, 1991.

2nd Investigation: Provided publication list regarding Ground Level Event GLE 69

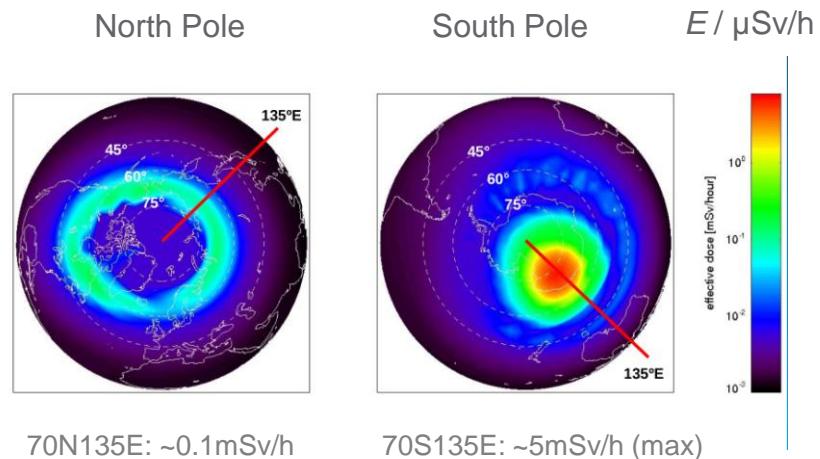
- Belov, A. V., Eroshenko, E. A., Mavromichalaki, H., Plainaki, C., and Yanke, V. G. (2005). Ground level enhancement of the solar cosmic rays on January 20, 2005. In International Cosmic Ray Conference, volume 1 of International Cosmic Ray Conference, page 189.
- Bombardieri, D. J., Duldig, M. L., Humble, J. E., and Michael, K. J. (2008). An Improved Model for Relativistic Solar Proton Acceleration Applied to the 2005 January 20 and Earlier Events. *Astrophys J*, 682:1315–1327.
- Bütkofer, R., Flückiger, E. O., Desorgher, L., and Moser, M. R. (2006). Analysis of the GLE on January 20, 2005: an update. In 20th European Cosmic Ray Symposium, Lisbon (Portugal).
- Bütkofer, R., Flückiger, E. O., Desorgher, L., and Moser, M. R. (2007). The extreme solar cosmic ray particle event on 20 January 2005 and its influence on the radiation dose rate at aircraft altitude. *Sci. Total Environ.*, 391(2).
- Dvornikov, V. M., Kravtsova, M. V., Lukovnikova, A. A., and Sdobnov, V. E. (2007). Variations in the cosmic-ray rigidity spectrum during events of January 2005. *Bulletin of the Russian Academy of Science, Phys.*, 71:942–944.
- Makmutov, V. S., Bazilevskaya, G. A., Vashenyuk, E. V., Balabin, Y. V., and Gvozdevsky, B. B. (2008). Solar proton spectra in the 20 January 2005 GLE: Comparison of simulations with balloon and neutron monitor observations. In Physics of Auroral Phenomena, Proc. XXXI Annual Seminar, Apatity, pp 122–125.
- Matthiä, D. (2009). The Radiation Environment in the Lower Atmosphere A Numerical Approach. PhD Thesis, Mathematisch-Naturwissenschaftliche Fakultät der Christian-Albrechts-Universität zu Kiel.
- Matthiä, D., Heber, B., Reitz, G., Meier, M., Shiver, L., Berger, T., and Herbst, K. (2009). Temporal and spatial evolution of the solar energetic particle event on 20 January 2005 and resulting radiation doses in aviation. *Journal of Geophysical Research (Space Physics)*, 114:8104.
- Plainaki, C., Belov, A., Eroshenko, E., Mavromichalaki, H., and Yanke, V. (2007). Modeling ground level enhancements: Event of 20 January 2005. *Journal of Geophysical Research (Space Physics)*, 112:4102.
- Vashenyuk, E. V., Balabin, Y. V., Bazilevskaya, G. A., Makmutov, V. S., Stozhkov, Y. I., and Svirzhevsky, N. S. (2005a). Solar Particle Event 20 January, 2005 on stratosphere and ground level observations. In International Cosmic Ray Conference, volume 1 of International Cosmic Ray Conference, p. 213.
- Vashenyuk, E. V., Balabin, Y. V., Gvozdevsky, B. B., Karpov, S. N., Yanke, V. G., Eroshenko, E. A., Belov, A. V., and Gushchina, R. T. (2005b). Relativistic solar cosmic rays in January 20, 2005 event on the ground based observations. In International Cosmic Ray Conference, volume 1 of International Cosmic Ray Conference, p. 209.
- Vashenyuk, E. V., Milkroshnichenko, L. I., Balabin, Y. V., Perez-Peraza, J., and Gallegos-Cruz, A. (2007). Two-component features of the two largest GLEs: February 23, 1956 and January 20, 2005. In International Cosmic Ray Conference, volume 1 of International Cosmic Ray Conference, pp. 249–252.

Neutron monitor data and calculated dose rates during Ground Level Event GLE69

Data of selected stations of the worldwide Network of neutron monitors during GLE69



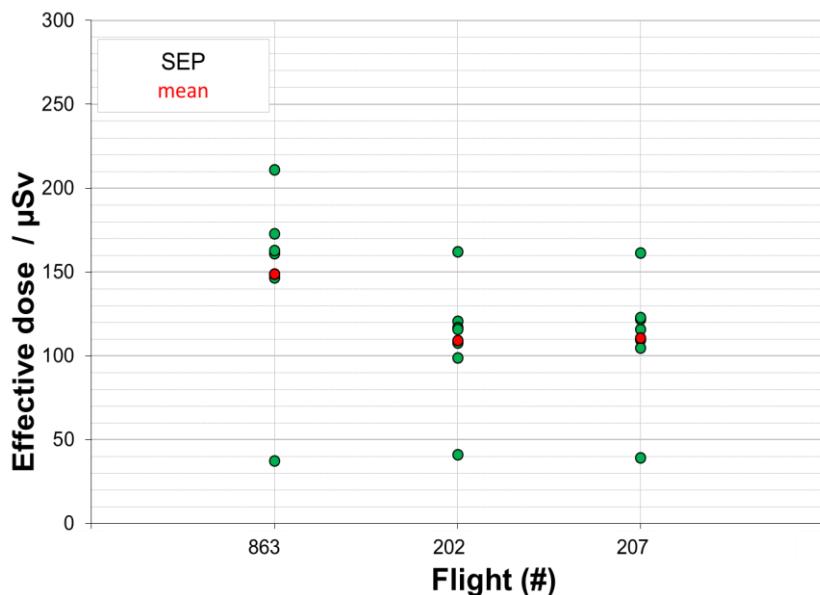
Calculated effective dose rate during the maximum phase of GLE 69 at 10.5 km



Bütikofer, EURADOS WG11/TG3 Meeting London, Sept. 2014

Results 1st Investigation: Ground Level Event in the style of GLE 42

Effective route dose, E due to SEP as obtained by the different codes

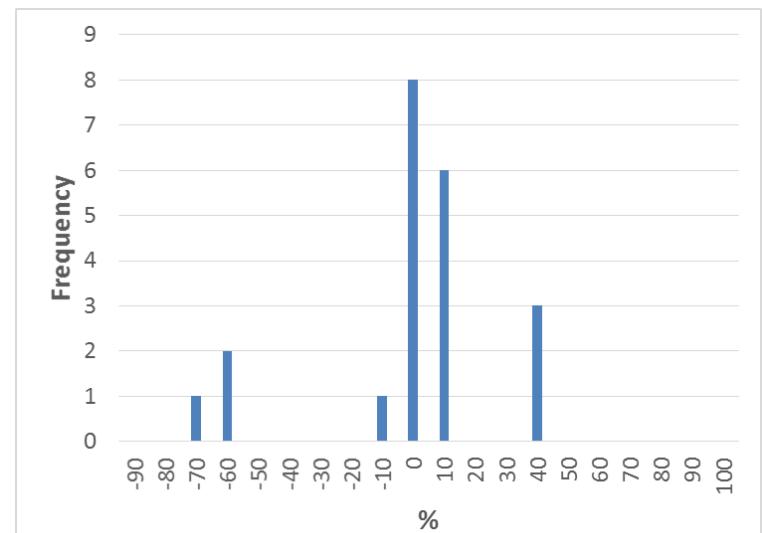


(863) Atlantic Ocean:
San Francisco – Paris

(202) North Pole:
Chicago – Beijing

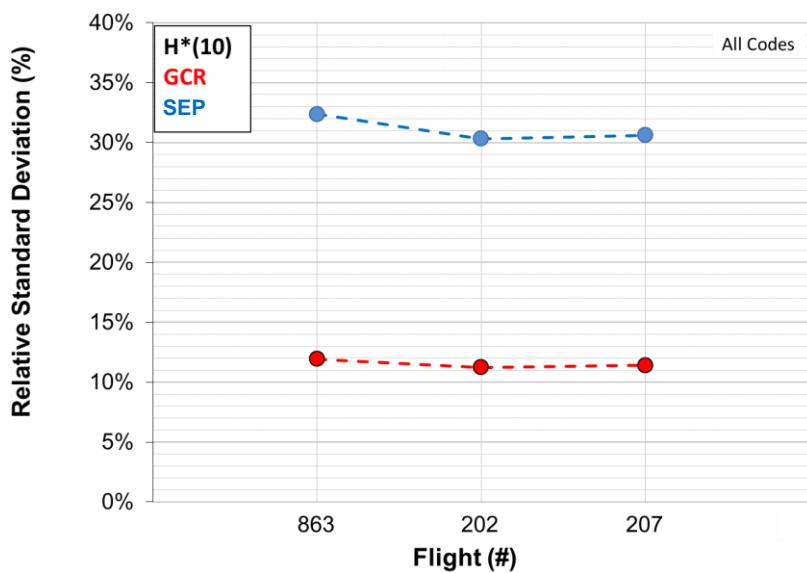
(207) Southern hemisphere:
Sydney – Johannesburg

Frequency distribution of effective route dose, E relative to the mean

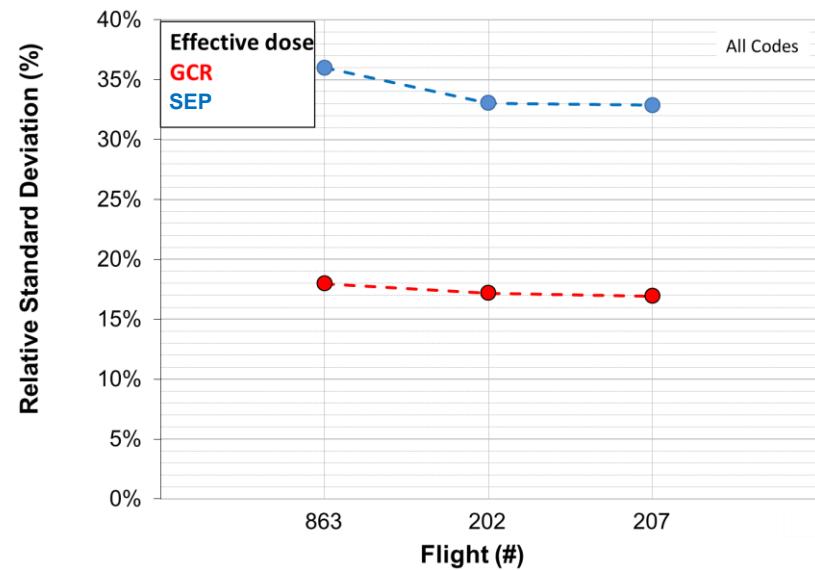


Results 1st Investigation: Ground Level Event in the style of GLE 42

Relative standard deviation
ambient dose equivalent, $H^*(10)$

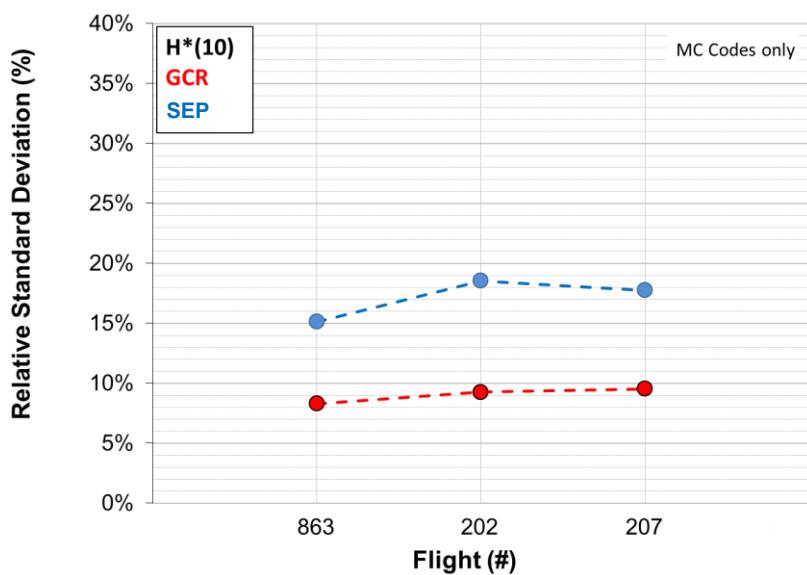


Relative standard deviation
effective dose, E

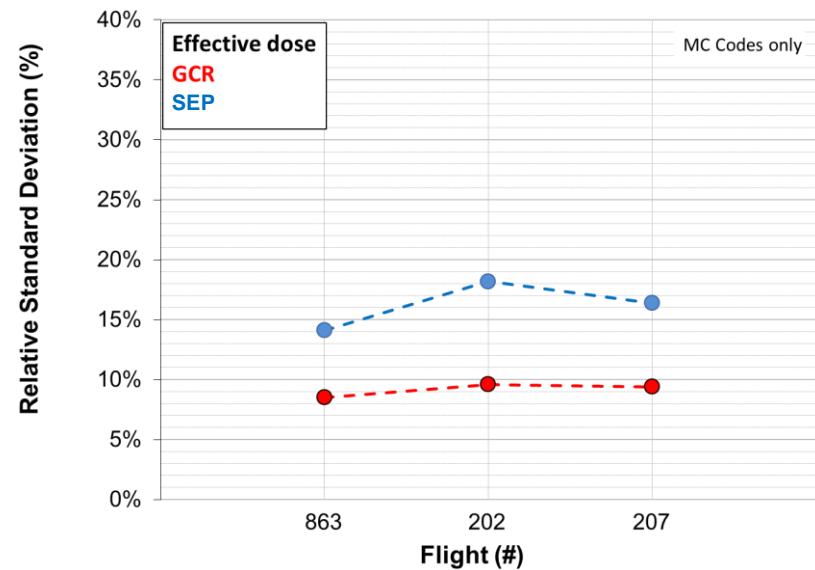


Results 1st Investigation: Ground Level Event in the style of GLE 42 Monte Carlo Codes

Relative standard deviation
ambient dose equivalent, $H^*(10)$

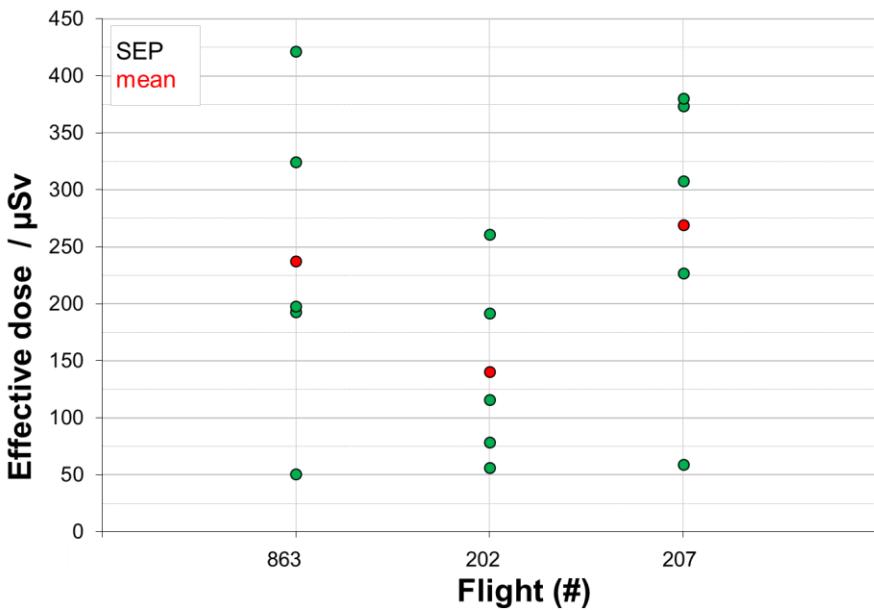


Relative standard deviation
effective dose, E

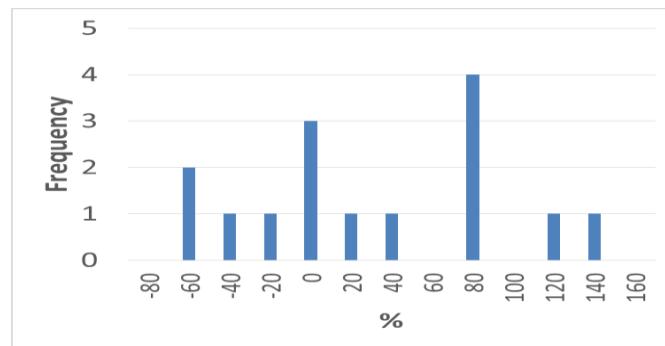


Results 2nd Investigation: Ground Level Event GLE 69

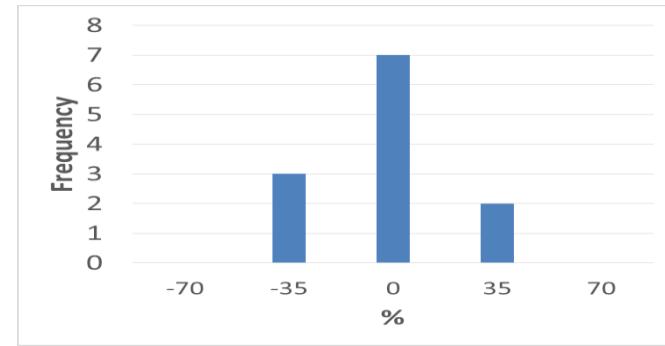
Effective route dose, E due to SEP as obtained by the different codes



All codes



Monte Carlo codes



Preliminary Conclusions and Future Activities

- Relative standard deviation of the mean route dose due to SEP for two ground level event investigations:

	1 st Investigation		2 nd Investigation	
Type of Code	E	$H^*(10)$	E	$H^*(10)$
all types	$\pm 35\%$	$\pm 30\%$	$\pm 75\%$	$\pm 70\%$
Monte Carlo	$\pm 20\%$	$\pm 20\%$	$\pm 35\%$	$\pm 40\%$

- Significant dependency of the used **proton input spectra**
- Next activity: Comparison of results computed with different codes with published experimental data (e.g. flight during GLE 42, **London – New York**)
- Publish results in EURADOS Report WG11/TG3